The field trials in the Salt Farm Texel, The Netherlands, to find the tolerance of potato to soil salinity, yield yearly different results

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Abstract

In the Salt Farm Texel, The Netherlands, field experiments have been conducted to detect the tolerance of various potato varieties to soil salinity. Some varieties have been tested during a number of years. The longest test duration was 6 years for the variety Miss Mignonne and 5 years for Achilles. The results were quite different from year to year, not only concerning the salinity tolerance, but also with respect to yield level.

This paper summarizes the yearly results of these two varieties and describes the yearly differences. It uses two different methods: (1) the Maas-Hoffman model and (2) the PartReg method. These also yield in some cases different results.

The question what to do with the variation in outcomes is raised and discussed. Partly some answers can be given, but the answer to query what to do with the annual differences remains uncertain.

Contents

1. Introduction

The Salt Farm Texel, (SFT) has a facility of 1 ha split-up in 56 fields, grouped in 8 randomly selected fields that receive irrigation with one of seven irrigation salinities of the irrigation water, expressed in Electric Conductivities (ECi) in a rotational system with one or two irrigation events per day. The irrigation water is obtained by controlled mixing of fresh dune water with sea water. The target irrigation ECi values are 0, 4, 8, 12, 16, and 20 dS/m with the aim to create corresponding soil salinities.

The soil salinity was measured regularly and expressed in the Electric Conductivity of the extract of a saturated soil paste (ECe in dS/m), with the aim to relate these values crop production, as is standsrd in international literature. Also, the salinity of the soil moisture (ECsm) was measured. The relation between ECi and ECsm shows variations, but the general trend is that the ECsm corresponds reasonably well with the ECi (*figure 1*).

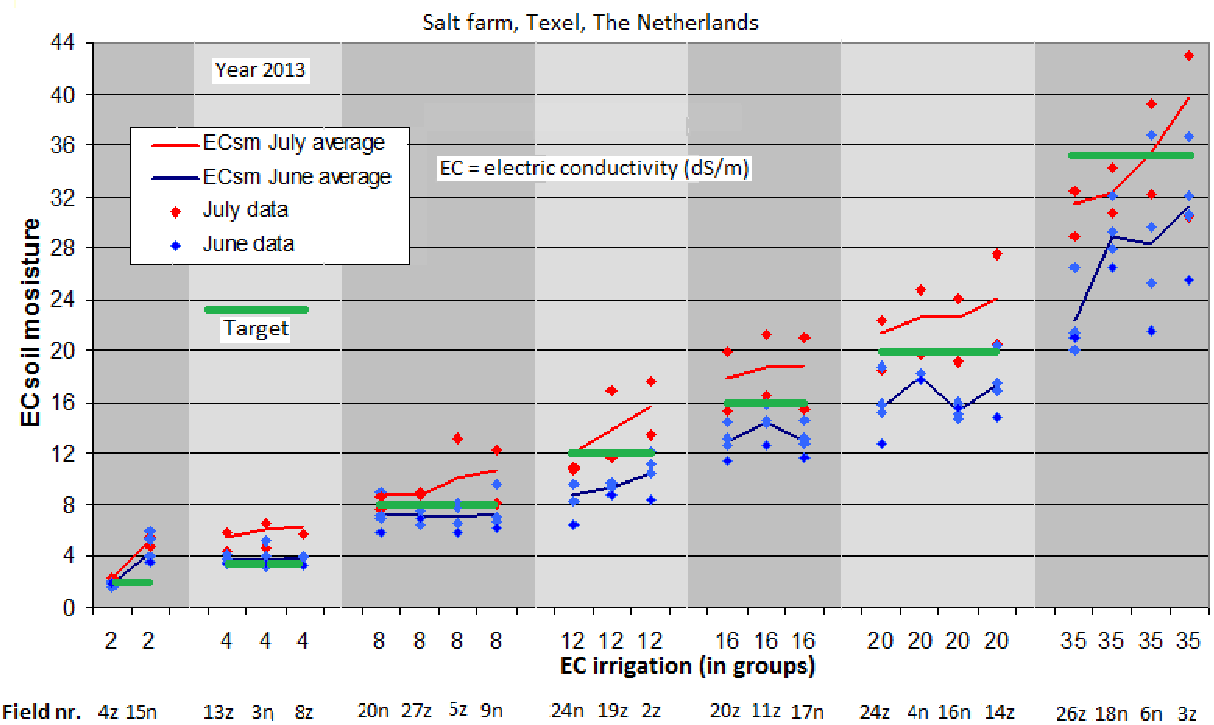


Figure 1. *Example (year 2013) of the relation between salinity of the irrigation water and that of the soil moisture. In July the EC soil moisture is somewhat higher than in June. There is variation within each irrigation treatment, but the variation is around the targets and the overall trend between the treatments show a clear correspondence.*

In this paper the data on ECe and yield are analyzed with the Maas-Hoffman (MH) model and the PartReg method to find the maximum salt tolerance level (or salt tolerance index, STI) of the crops. Van Straten et al., 2019 [*Reference 1*] preferred the van Genuchten-Hoffman (or van Genuchten-Gupta model which was published earlier), but this model is not fit to detect the STI value and will therefore not be used here [*Reference 2, Appendix A*].

2. The Maas-Hoffman (MH) model

The MH model will be applied to the potato varieties Achilles (Ach) and Miss Mignonne (MiMi) separately.

2A. Potato Achilles (Ach), 2012-2016, MH model

In *figure 2* one sees a graph of the segmented regression of Ach yield versus soil salinity performed with the SegRegA software [*Reference 3*]. The regression is of type 3 which equals the Maas-Hoffman (MH) model.

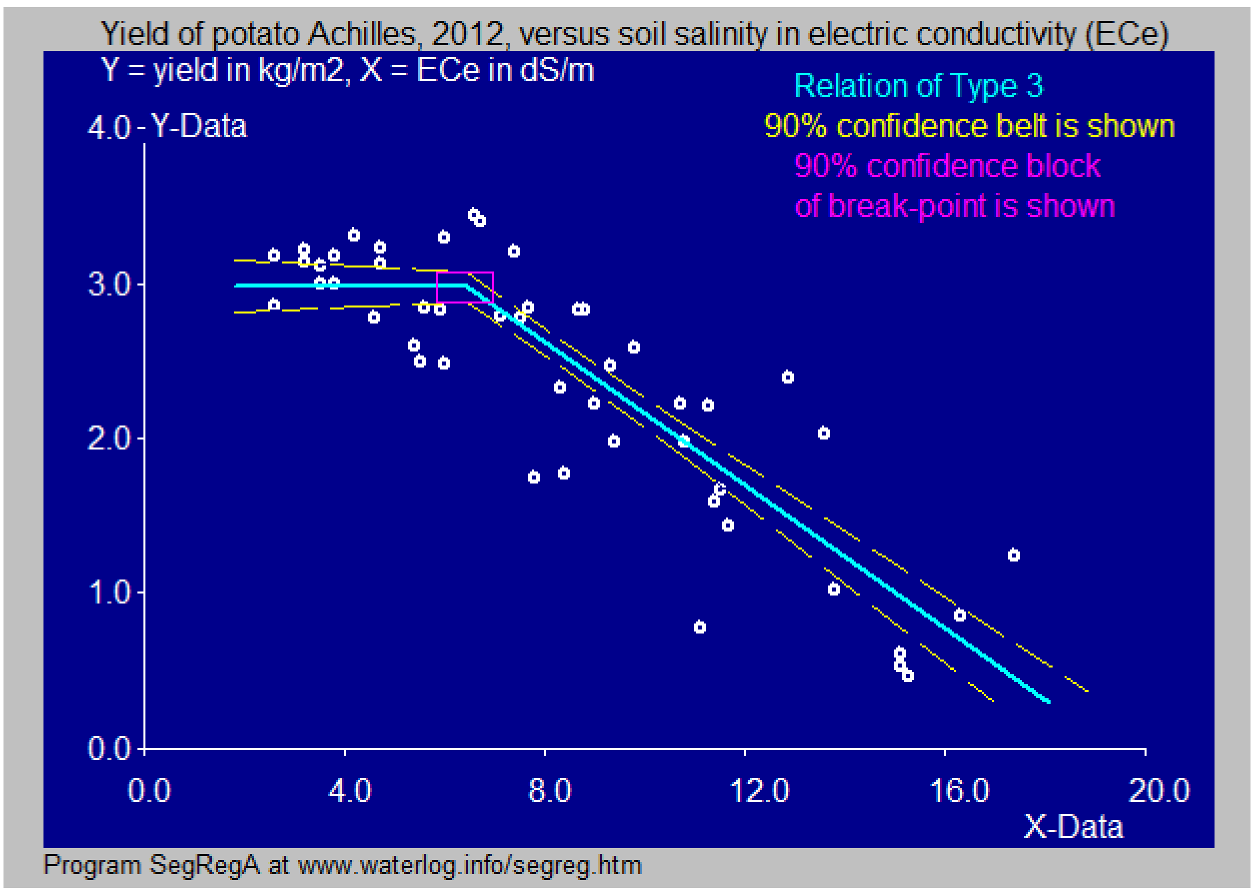


Figure 2. *Segmented regression of yield (Y) on soil salinity (X) for potato Achilles in 2012. At a soil salinity of ECe = 6.5 one finds a breakpoint below which the yield is not negatively affected yj the salinity while beyond it the yield declines with increasing ECe.* This value is the maximum salt tolerance level (or salt tolerance index, STI).

The segmented regression, as used in SegRgA, minimizes the sum of squares of the deviations between the simulated and observed yields over the entire domain(this is the so called least squares method, LSM) to find the optimum values of the regression parameters so that the goodness of fit is maximized.

Figure 3 depicts the attempts to produce the Ach MH model for all the years 2012-2016 in one graph.

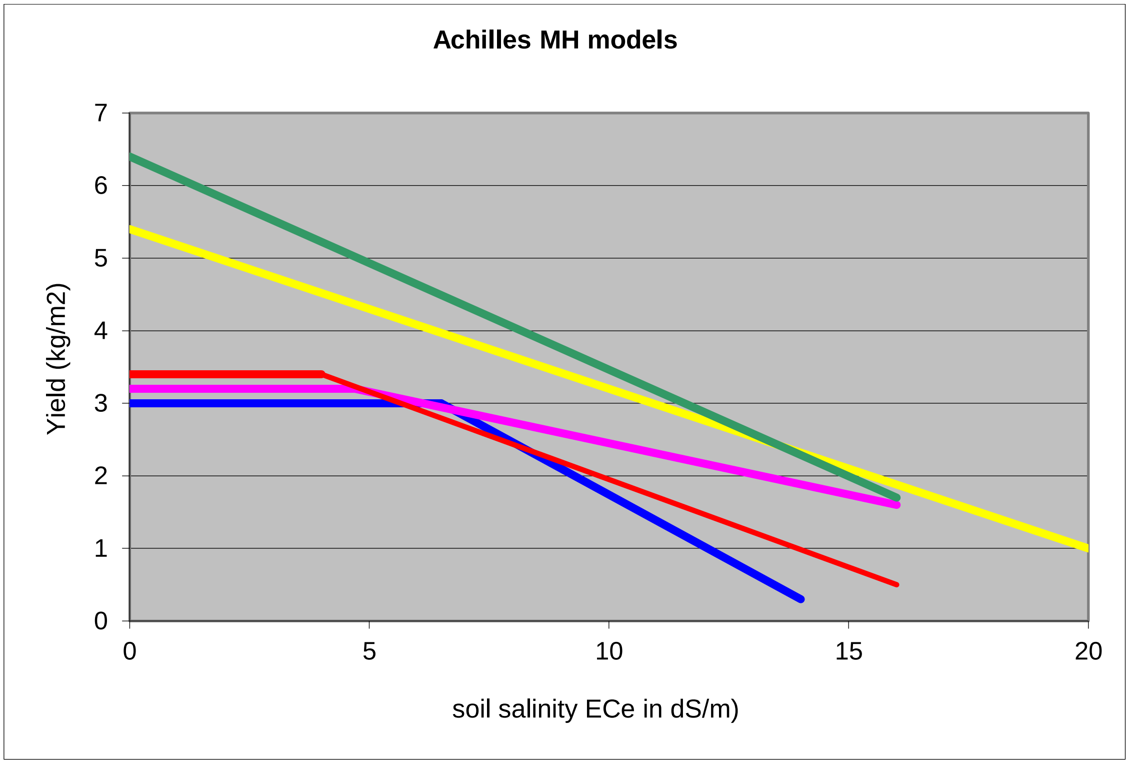


Figure 3. *Attempts to depict the MH models for Achilles in all years 2012 to 2016.*
Legend: 2012-blue, 2013-yellow, 2014-purple, 2015-green, 2016-red.
For the years 2013 (yellow) and 2015 (green) no breakpoint could be detected, hence there salt tolerance index is zero: the yields decline immediately when the soil salinity increases, there is no safe zone.

The graphs of *figure 3* make it clear the years 2012 (blue), 2014 (purple) and 2016 (red) have low yields of around 3 kg/m2. For comparison: the farmers in the Netherlands need yields of about 60 tons/ha (6 kg/m2) to earn a decent income.

If it can be decided that the red purple and blue graphs are not representative for the determination of the salt tolerance index (STI), the it can be concluded that potato Achilles has no salt tolerance at all because the admissible yellow and green graphs have no breakpoint.

2B. Potato Miss Mignonne (MiMi), 2012-2016, MH model

In *figure 4* one sees a graph of the segmented regression of MiMi yield versus soil salinity performed with the SegRegA software [*Reference 3*]. The regression is of type 3 which equals the Maas-Hoffman (MH) model.

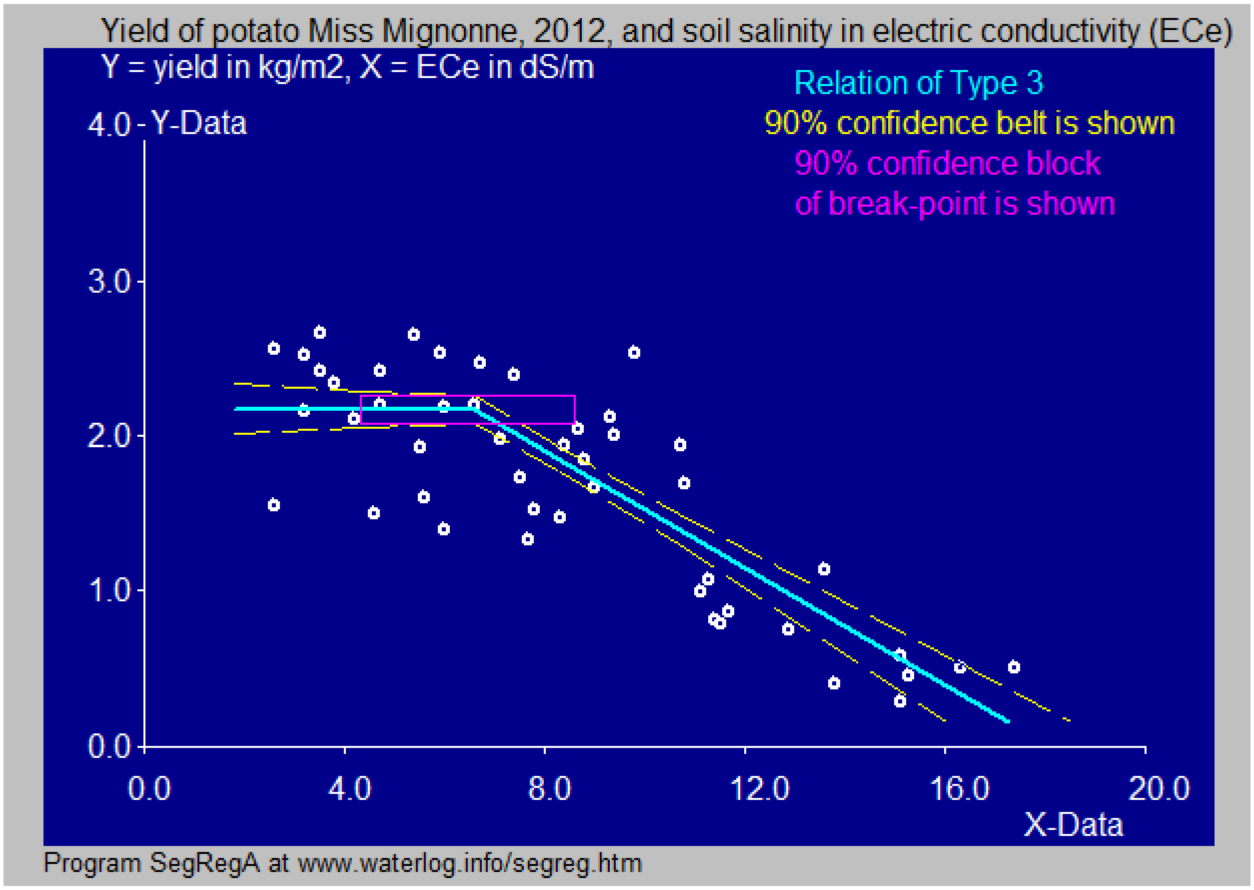


Figure 4. *Segmented regression of yield (Y) on soil salinity (X) for potato Miss Mignonne in 2012. At a soil salinity of ECe = 6.6 one finds a breakpoint below which the yield is not negatively affected yj the salinity while beyond it the yield declines with increasing ECe.* This value is the maximum salt tolerance level (or salt tolerance index, STI).

Figure 5 depicts the attempts to produce the MiMi MH model for all the years 2012-2017 in one graph.

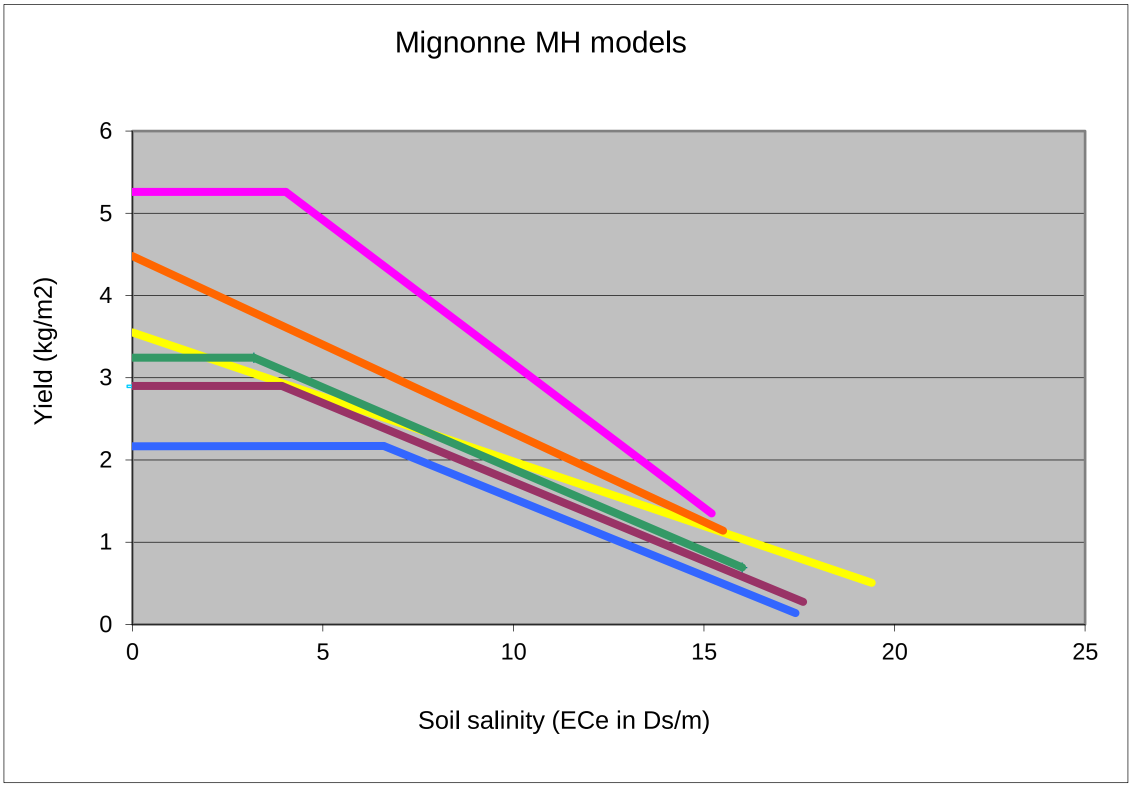


Figure 5. *Attempts to depict the MH models for Mignonne in all years 2012 to 2016.*
Legend: 2012-blue, 2013-yellow, 2014-purple, 2015-green, 2016-red, 2017-brown
For the years 2013 (yellow) and 2015 (green) no breakpoint could be detected, hence there salt tolerance index is zero: the yields decline immediately when the soil salinity increases, there is no safe zone.

The graphs of *figure 5* make it clear the years 2012 (blue), 2015 (green) and 2017 (brown) have low yields of around 3 kg/m2 or less. For comparison: the farmers in the Netherlands need yields of about 60 tons/ha (6 kg/m2) to earn a decent income.

The year 2014 (purple) shows a high yield level and a breakpoint at ECe=4.0 dS/m. This is in contrast with the findings for 2014 (purple) in *figure 3* (for Achilles), that reveals a low yield.

If it can be decided that the red purple and blue graphs are not representative for the determination of the salt tolerance index (STI), the it can be concluded that potato Achilles has no salt tolerance at all because the admissible yellow and green graphs have no breakpoint.

3. The PartReg method

The PartReg will be applied to the potato varieties Achilles (Ach) and Miss Mignonne (MiMi) separately.

3A. Potato Achilles (Ach), 2012-2016, PartReg method

In *figure 6* one sees a graph of the partial regression of Ach yield versus soil salinity performed with the PartReg software [*Reference 4*].

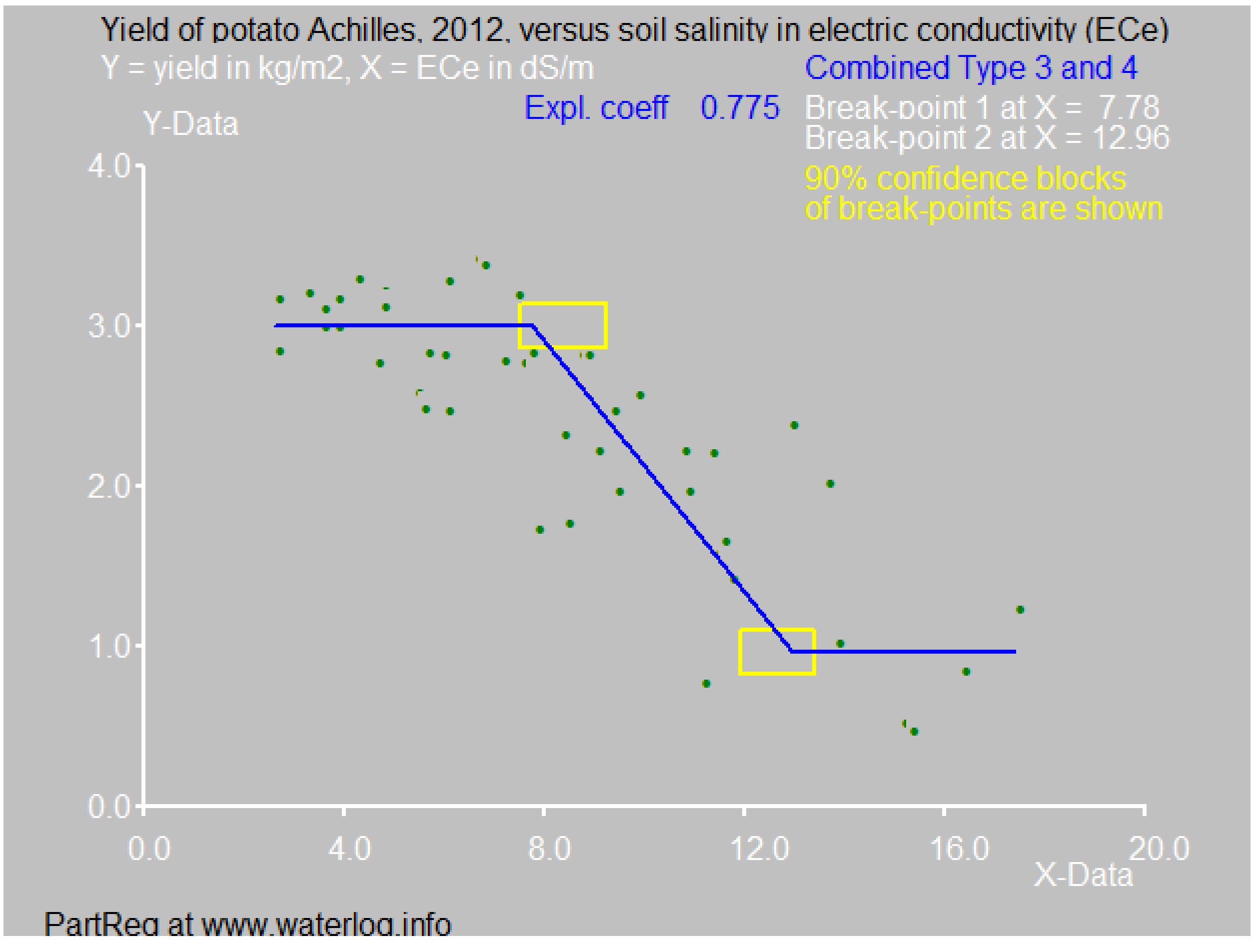


Figure 6. The PartReg method applied to *yield (Y) and soil salinity (X) data for potato Achilles in 2012. At a soil salinity of ECe = 7.8 one finds a breakpoint below which the yield is not negatively affected by the salinity while beyond it the yield declines with increasing ECe.* This value is the maximum salt tolerance level (or salt tolerance index, STI).

Unlike the segmented regression (see *figure 2*), PartReg does not use the least squares method over the entire domain (LSM) , but it simply tries to detect horizontal stretches in the plot of Y versus X data. Data beyond these stretches remain separate. PartReg, therefore, is not a model, but a method.

It can be seen in *Figure 4* that the breakpoint at X=ECe=7.8 dS/m may serve as the salt tolerance index (STI) indication the save ECe range where the yield is not negatively affected by salinity.

This value (STI=7.8) is higher than the STI value in *figure 2* (6.5 dS/m) according to the MH model. The reason is that the horizontal tail-end for X values greater than 13 dS/m (as in *figure 8*) draws the breakpoint to the left when applying the LSM principle over the whole domain.

Figure 7 depicts the attempts to produce the Ach analysis by the PartReg method for all the years 2012-2016 in one graph.

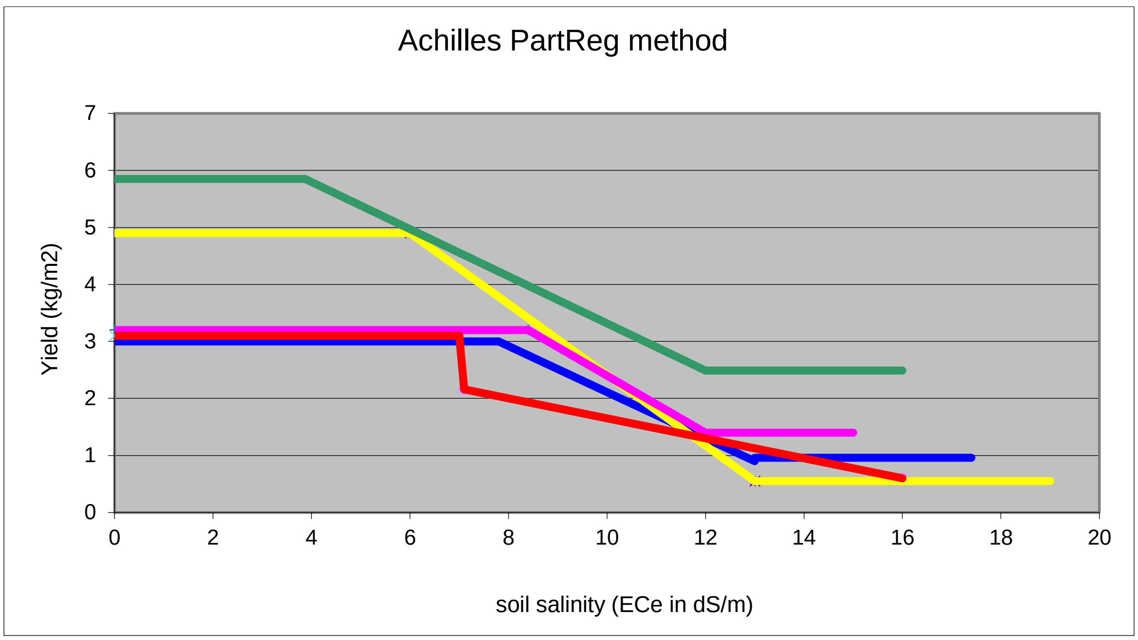


Figure 7. *Attempts to depict the PartReg result for Achilles in all years 2012 to 2016.*
Legend: 2012-blue, 2013-yellow, 2014-purple, 2015-green, 2016-red.

PartReg has detected two horizontal stretches, one at the beginning and one at the end of the graphs, except in the case of the year 2016 (red). When two stretches are present, a Z-type function is obtained.

The results of year 2016 (red) show a jump at the breakpoint, indicating that the sloping line to the right has been made independently of the data to the left. In this case the sloping line is found by linear regression of the data beyond the breakpoint only, not considering the entire domain.

The graphs for the years 2012 (blue), 2014 (purple) and 2016 (red) have low maximum yield levels of around 3 kg/m2, just like in *figure 3* made with the MH model. For comparison: the farmers in the Netherlands need yields of about 60 tons/ha (6 kg/m2) to earn a decent income.

3B. Potato Miss Mignonne (MiMi), 2012-2016, PartReg method

In *figure 8* one sees a graph of the MiMi yield versus soil salinity performed with the PartReg software [*Reference 4*].

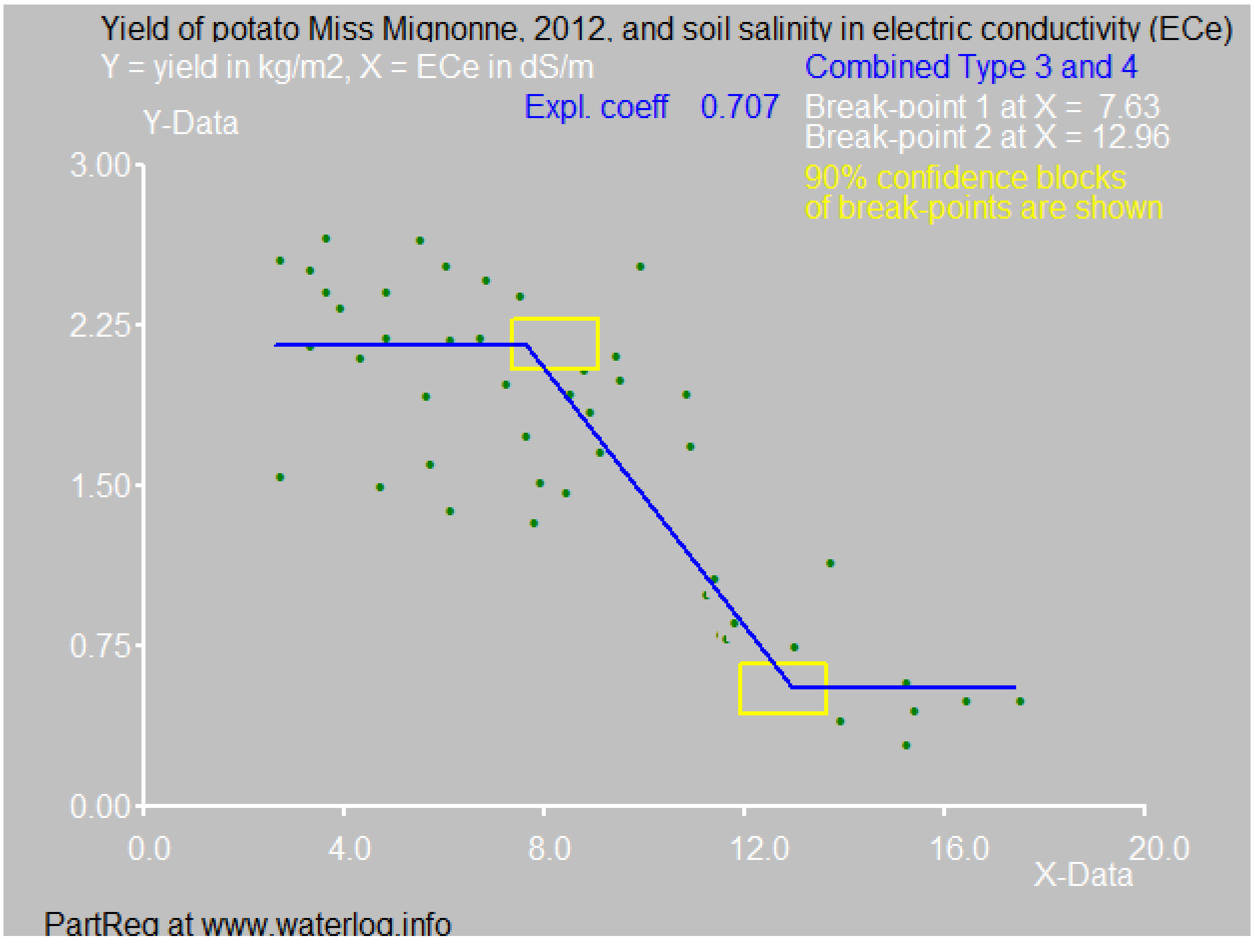


Figure 8. The PartReg method applied to *yield (Y) and soil salinity (X) data for potato Mignonne in 2012. At a soil salinity of ECe = 7.6 one finds a breakpoint below which the yield is not negatively affected by the salinity while beyond it the yield declines with increasing ECe.* This value is the maximum salt tolerance level (or salt tolerance index, STI).

Unlike the segmented regression (see *figure 2*), PartReg does not use the least squares method over the entire domain (LSM) , but it simply tries to detect horizontal stretches in the plot of Y versus X data. Data beyond these stretches remain separate. PartReg, therefore, is not a model, but a method.

It can be seen in *figure 8* that the breakpoint at X=ECe=7.6 dS/m may serve as the salt tolerance index (STI) indication the save ECe range where the yield is not negatively affected by salinity.

This value (STI=7.6) is higher than the STI value in *figure* 4 (6.6 dS/m) according to the MH model. The reason is that the horizontal tail-end for X values greater than 13 dS/m (as in *figure 8*) draws the breakpoint to the left when applying the LSM principle over the whole domain.

Figure 9 depicts the attempts to produce the Ach analysis by the PartReg method for all the years 2012-2016 in one graph.

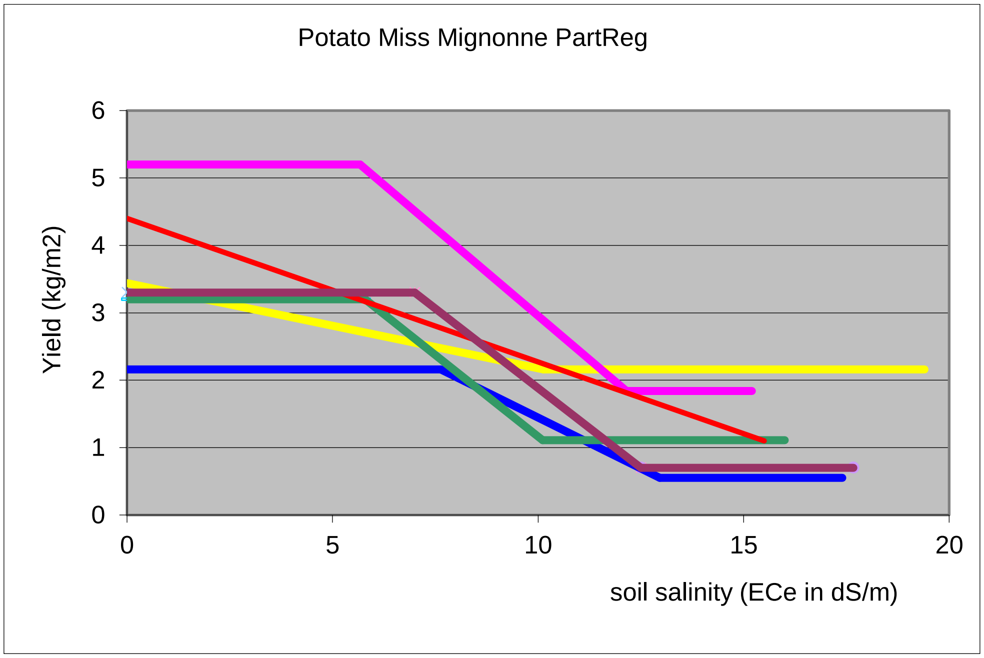


Figure 9. *Attempts to depict the PartReg result for Minonne in all years 2012 to 2017.*
Legend: 2012-blue, 2013-yellow, 2014-purple, 2015-green, 2016-red, 2017-brown.

For the year 2016 (red) no breakpoint could be detected, hence here the salt tolerance index is zero: the yields decline immediately when the soil salinity increases, there is no safe zone. This confirms the situation in *figure 5* for the MH model.

Similarly, for the year 2013 (yellow) no first horizontal stretch could be established and the yield descends immediately when the ECe value is greater than zero. This also agrees with the situation in *figure 5* for the MH model.

4. Summary and conclusions

The following two tables give a summary of the findings of the Achilles and Miss Minonne yield data versus soil salinity analyzed with the MH model and the PartReg method.

Table 1. *Three characteristics of the MH model and the PartReg method applied to the potato cultivar Achilles for the years 2012 to 2067 as depicted in the above figures 3 and 5. Low yields are presented in orange color.*

Year	Breakpoint (BP, tolerance level) in dS/m		Maximum yield (kg/m2)		Goodness of fit (R^2) in %	
	MH model	PartReg method	MH model	PartReg method	MH model	PartReg method
2012	6.5	7.8	2.3	3.0	75	78
2013	0	6.0	5.4	4.9	48	55
2014	4.7	8.4	3.2	3.2	58	64
2015	1.3	3.8	6.6	5.9	88	88
2016	4.0	7.0	3.4	3.5	69	67

In *table 1*, high yields, like in 2013 and 2015 are associated with low tolerance levels and vice versa. Low yield are indicated in orange color.

Table 2. *Three characteristics of the MH model and the PartReg method applied to potato cultivar Miss Mignonne for the years 2012 to 2017 as depicted in the above figures 7 and 9. Low yield are indicated in orange color.*

Year	Breakpoint (BP, tolerance level) in dS/m		Maximum yield (kg/m2)		Goodness of fit (R^2) in %	
	MH model	PartReg method	MH model	PartReg method	MH model	PartReg method
2012	6.6	11.3	2.2	2.0	71	71
2013	0	0	3.6	3.6	53	53
2014	4.0	9.4	5.3	4.8	90	86
2015	3.2	8.3	3.2	3.1	79	88
2016	0	0	4.5	5.2	78	78
2017	3.9	7.0	3.3	3.2	90	90

Contrary to *table 1*, in which high yields are associated with low tolerance levels and vice versa. in Table 2 the relation between yield level and salt tolerance is not clear, except for year 2012 when there is a low yield with a high tolerance level. The fact that the relation is not clear makes it difficult to draw a general conclusion about this relation.

It is not known why the annual yields are so variable [*Reference 5*]. This hampers the formulation of significant statements about the salt tolerance of both potato cultivars.

5. References

[Reference 1] G. van Straten et al., 2019, "*An improved methodology to evaluate crop salt tolerance from field trials*". On line: https://www.sciencedirect.com/science/article/pii/S0378377418310370)

[Reference 2]
R.J. Oosterbaan, 2021. Methods to evaluate crop salt tolerance from field trials, a critical review of the Salt Farm Texel article entitled: "An improved methodology to evaluate crop salt tolerance from field trials", which gives no improvement at all, to the contrary.

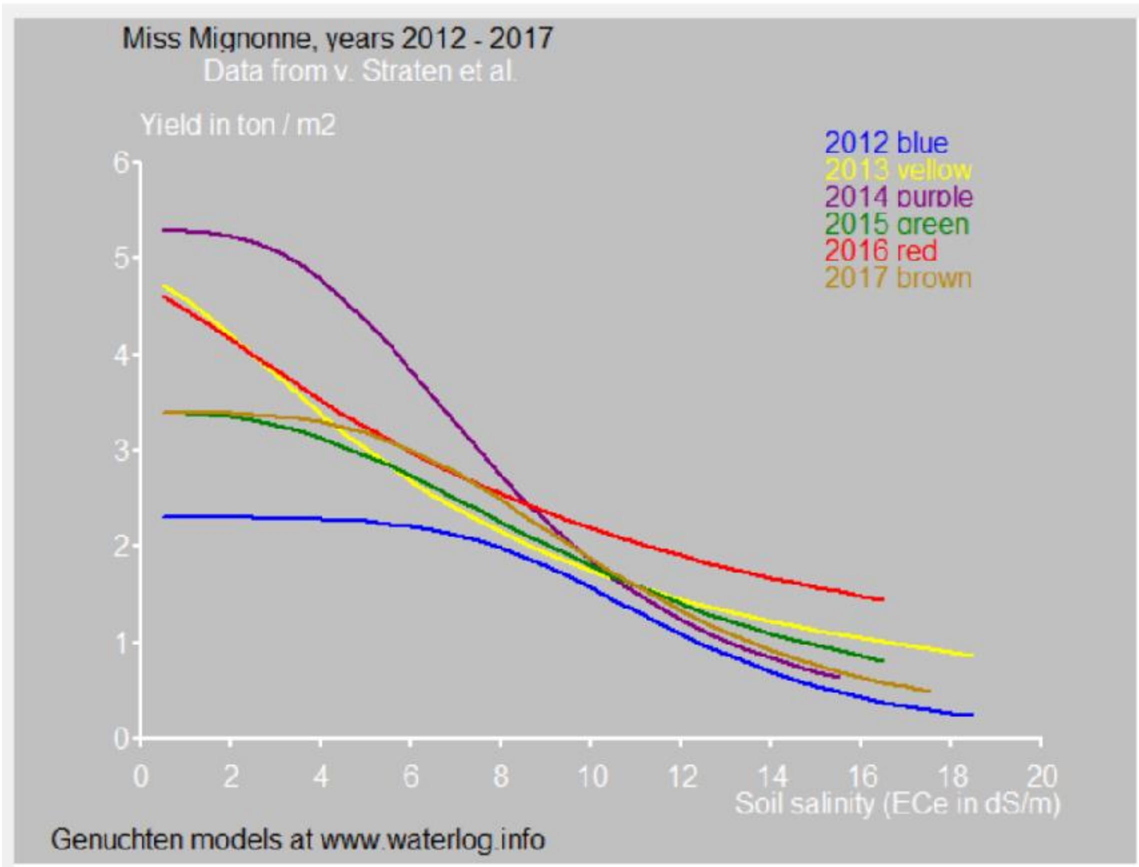
[Reference 3]
SegRegA, free software for segmented regression analysis. Download from: https://www.waterlog.info/segreg.htm

[Reference 4].
PartReg, free software for detecting horizontal stretches in Y-X data graphs. Download from: https://www.waterlog.info/partreg.htm

[Reference 5]
Van Straten et al. (2021]. "*Estimating cultivar-specific salt tolerance model parameters from multi-annual field tests for identification of salt tolerant potato cultivars*". https://doi.org/10.1016/j.agwat.2021.106902

6. Appendix A. (van Genuchten model and Mignonne)

The next figure gives an overview of graphs of the yield of potato cultivar Miss Mignonne versus soil salinity for the years 2012 to 2017 using the van Genuchten-Gupta model



In the above figure no breakpoints can be detected and it is difficult to fix the salt tolerance index STI, as could be found with the Maas-Hoffman model and the PartReg method.

In the years 2016 (yellow) and 2016 (red) the flattening of the curves towards the lower values of soil salinity is absent. According to the MH model and the PartReg method the soil salinity tolerance index (STI) is zero here.

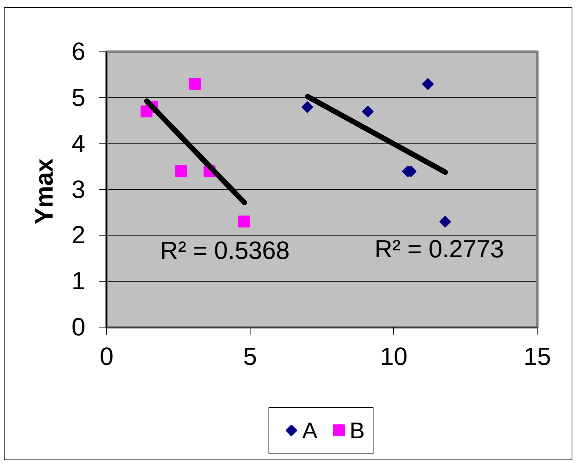
It is difficult to find from these curves a single value for the salt tolerance index. Van Straten et al. suggest the soil salinity at which the yield is 90% of the maximum yield where the soil salinity is zero [*Reference 1*]. However this suggestion is arbitrary [*Reference 2*].

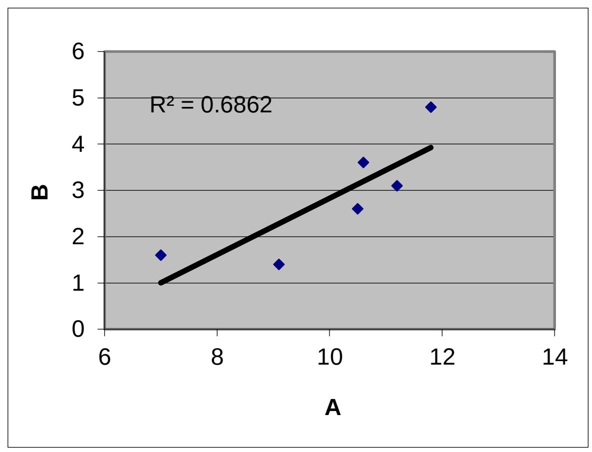
The van Genuchten-Gupta model can be written as $Y = Ymax / [\ 1 + (X / A)^{B}\ ]$, where Y = yield, Ymax = maximum yield, X = soil salinity, while A and B are parameters to be determined by the least squares method

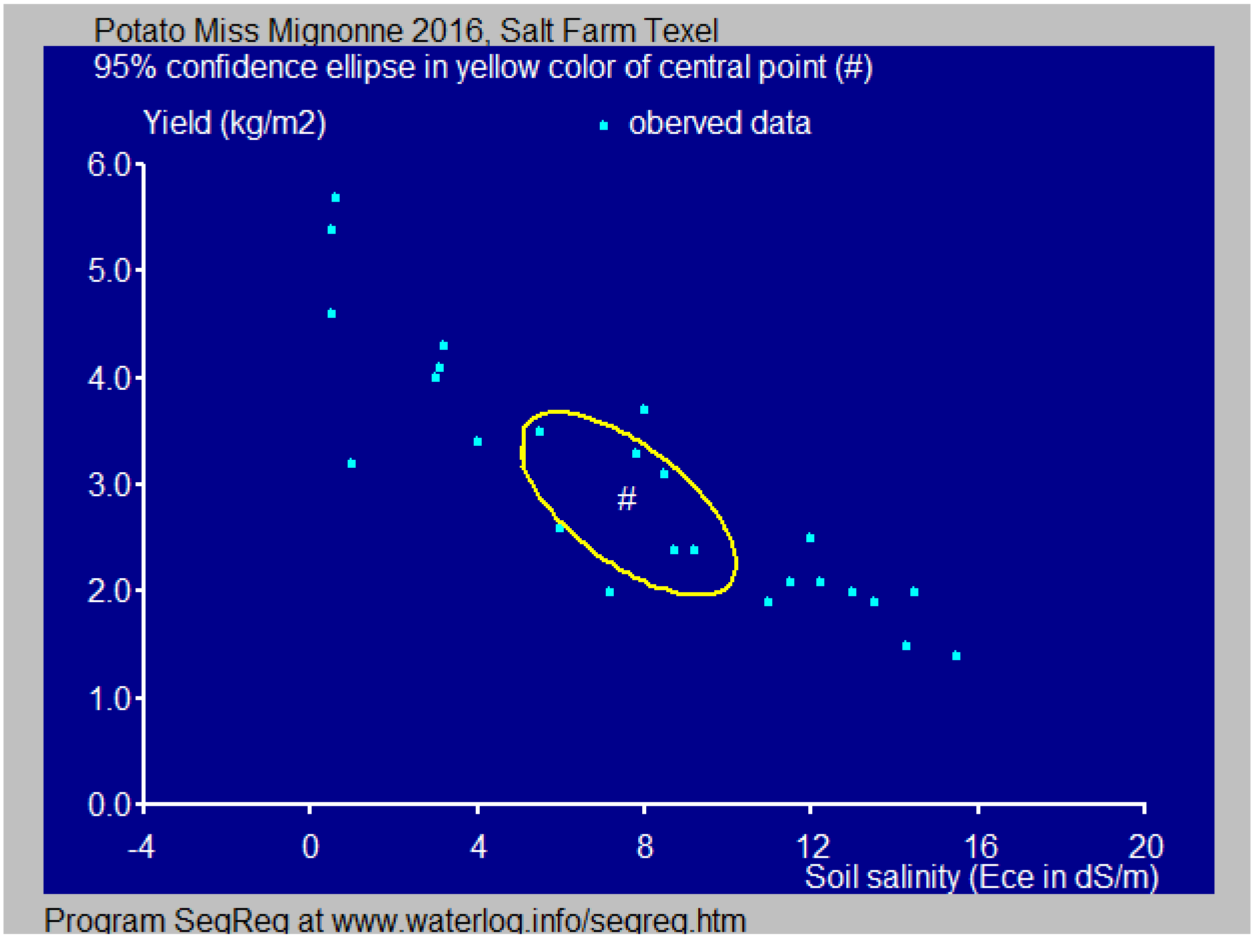
The following table gives an overview of the values of the parameters of the van Genuchten model for each year.

Year	Ymax (kg/m^2)	A	B	Goodness of fit (R^2) in %
2012	2.3	11.8	4.8	72
2013	4.8	7.0	1.6	65
2014	5.3	11.2	3.1	90
2015	3.4	10.5	2.6	87
2016	4.7	9.1	1.4	80
2017	3.4	10.6	3.6	90

The relational trends of the parameters are shown in the next table. The relation between Ymax and B is weak, the other relations are better.







A 95% confidence ellipse of the parameters (average X, average Y, indicated by #) in the case of potato Miss Mignonne 2016 is depicted herewith in yellow color.

Usually such ellipses are seldom required. The indication of the standard error of the parameters is sufficient. If required, the confidence interval can be calculated using Student's probability distribution with software like in https://www.waterlog.info/t-tester.htm

The van Genuchten-Hoffman (or rather the van Genuchten-Gupta) model does not use the parameter average Y. To find the standard error of its actual parameters, of which actually only one value is found, one requires the Monte Carlo simulation by creating a large number of random sets of data using the equation determined and thus finding a range of parameter values from which their standard error can be found

For the van Genuchten model such a complicated procedure is not necessary because it does not produce a salt tolerance index based on a breakpoint but only on the X value at the arbitrary 90% yield value, for which no standard error can be found as it is not a parameter.

7. Appendix B. (Questionable combination of relative Achilles data)

The following figure, found in the Salt Farm Brochure, written by A. de Vos et al. (2016) at:
https://library.wur.nl/WebQuery/wurpubs/fulltext/409817
gives the relative yield in % of 4 years combined versus soil salinity. This results in years with high yields and low salt tolerances and in years with low yields and high salt tolerances combined in one graph (compare with *figure 7* and *figure 9*).

It is questionable whether this procedure gives a correct picture of the salt tolerance of the crop because the data with low yield level and high tolerance should not be considered representative. In addition, the scatter of the points is enormous.